The impact of medical procedure and product innovation on U.S. mortality, 1999-2019: Evidence from Medicare Coverage Determinations

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2 January 2025

No financial support was received for this research.
All data used are publicly available on the internet.

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Abstract

During the last 40 years, there have been many innovations in medical services, supplies, and equipment: the number of Healthcare Common Procedure Coding System (HCPCS) codes ever established increased from 4994 in 1984 to 17,997 in 2023. We assess the impact that those innovations had on the mortality of Americans during the period 1999-2019 using a difference-in-differences research design: we investigate whether the diseases that were subject to more innovation exhibited larger declines in mortality. We use Medicare Coverage Determinations data to determine which disease(s) each HCPCS code is associated with. All the data used are publicly available on the internet.

We construct two types of measures of innovation associated with a disease: the long-run change in the *number* of HCPCS codes associated with the disease that had ever been established, and the long-run change in the *mean vintage* (year of HCPCS code establishment) of HCPCS codes associated with the disease that had ever been established. The estimates based on the two alternative innovation measures are qualitatively similar, but mortality is more strongly related to the mean vintage of HCPCS codes ever established than it is to the number of HCPCS codes ever established.

Our estimates indicate that the number of years of potential life lost before ages 85, 75, and 65 from a disease is significantly inversely related to the mean vintage of HCPCS codes associated with the disease that had ever been established 0-4 or 0-6 years earlier. Mean age at death from a disease is significantly positively related to the mean vintage of HCPCS codes associated with the disease that had ever been established 2-8 years earlier. The number of deaths from a disease is *not* significantly related to the mean vintage of HCPCS codes associated with the disease that had ever been established 0-8 years earlier.

In addition to assessing the impact that those innovations had on the mortality of all Americans, we assess the impact that they had on the mortality of different demographic groups, defined by education or race. Premature (before age 75) mortality of all education groups (people with 0-11 years, 12 years, or 13+ years of education) was reduced by medical innovation. Innovation may have increased the longevity of more educated people sooner than it increased the longevity of less educated people, perhaps because more educated people have earlier access to innovations, but innovation appears to have had similar long-run (after 7 or 8 years) effects on the longevity of the three education groups.

Premature (before ages 85, 75, and 65) mortality rates of Black Americans is not significantly related to the mean vintage of HCPCS codes that had ever been established 0-8 years earlier, but their mean age at death is significantly positively related to the mean vintage of HCPCS codes that had ever established 5-8 years earlier. Innovation may have increased the longevity of black people later than it increased the longevity of other racial groups, perhaps because black people had later access to innovations, but the long-run (after 5-8 years) effect of innovation on the longevity of black people appears to be similar to its effects on the longevity of other racial groups.

During the period 1999-2019, age-adjusted rates of premature (before ages 85, 75, and 65) mortality declined by about 20%. We cannot reject the null hypothesis that in the absence of biomedical innovation, the premature mortality rates would not have declined during the period 1999-2019. Some factors other than biomedical innovation (e.g., the decline in smoking rates and the increase in educational attainment) probably contributed to the decline in mortality. However, other factors (the increase in obesity and chronic condition prevalence) probably contributed to an increase in mortality.

I. Introduction

Each year in the U.S., health care insurers process over 5 billion claims for payment. Standardized coding systems are essential so that Medicare and other health insurance programs can process claims in an orderly and consistent manner. The Healthcare Common Procedure Coding System (HCPCS) was established in 1978 by the Federal government to standardize the reporting of medical services, supplies, and equipment, essentially creating a unified system for medical billing across different healthcare providers and payers.[1] While initially voluntary, the Health Insurance Portability and Accountability Act (HIPAA) of 1996 made the use of HCPCS codes mandatory for all healthcare transactions.

HCPCS is divided into 2 main subsystems — Level I and Level II. The American Medical Association (AMA) had already developed the Current Procedural Terminology (CPT) coding system in 1966, which became the basis for Level I HCPCS codes. The need for a separate coding system for non-physician services and supplies led to the creation of HCPCS Level II codes, which focus on items like drugs, devices, and durable medical equipment. As shown in Figure 1, the number of HCPCS codes ever established has increased substantially during the last 40 years. By the end of 1984, 4994 codes had been established. By the end of 2023, 17,997 codes had been established—a 260% increase.[2]

The establishment of a new Level II code requires approval by the CMS HCPCS Workgroup, which is made up of physicians and healthcare professionals within CMS, as well as other pertinent federal agencies such as the Department of Veterans Affairs and the Department of Defense (Gutmann (2024)).[3] In reviewing requests for new codes, the Workgroup considers whether a product performs a significantly different function or operates in a significantly different manner from items in existing coding categories. The company requesting the code must show in the application that there is a significant therapeutic distinction compared to existing coded treatments or products. The application includes other questions to determine

[1] The system was initially called the "HCFA Common Procedure Coding System" as "HCFA" was the previous name for the Centers for Medicare and Medicaid Services which manages HCPCS today.
[2] As shown in Appendix Table 1, the Restructured BETOS Classification System (RBCS) is a taxonomy that groups the 17,997 codes into clinically meaningful categories (N = 8) and subcategories (N = 53) (HealthData.gov (2024)). Appendix Table 2 shows the number of HCPCS codes ever established by 2000 and 2023, by RBCS category. Appendix Table 3 shows the number of services provided and total amount Medicare paid in 2019, by RBCS category and subcategory.
[3] Establishment of new Level I (CPT) codes is discussed in American Medical Association (2024).

why a new code is needed. For example, for devices, there are questions pertaining to the coding for the FDA predicate device, and why the new device should not be coded in the same manner.

The 260% increase during 1984-2023 in the number of HCPCS codes ever established suggests that there have been many innovations in medical services, supplies, and equipment.[4] The objective of this study is to assess the impact that those innovations had on the mortality of Americans during the period 1999-2019.[5] We will use a difference-in-differences research design: we will investigate whether the diseases that were subject to more innovation exhibited larger declines in mortality.[6] In addition to assessing the impact that those innovations had on the mortality of all Americans, we will assess the impact that they had on the mortality of different demographic groups, defined by education or race.

To implement this approach, we need to identify which disease(s) each HCPCS code is associated with. We will use data on Medicare Coverage Determinations (MCDs) to link HCPCS codes to disease (ICD-10-CM) codes. MCDs are made by CMS to determine if a medical service, procedure, or device is covered by Medicare. Medicare coverage is limited to items and services that are reasonable and necessary for the diagnosis or treatment of an illness or injury (and within the scope of a Medicare benefit category).

There are two types of MCDs: National Coverage Determinations (NCDs) and Local Coverage Determinations (LCDs). NCDs are binding determinations that are made for the entire country and apply to all Medicare beneficiaries. The Secretary of the Department of Health and Human Services makes the decision based on evidence, including medical and scientific information, FDA data, and clinical trial information. In some cases, CMS' own research is supplemented by an outside technology assessment and/or consultation with the Medicare Evidence Development & Coverage Advisory Committee (MEDCAC). The public can participate in the process.

When there is no national coverage policy, Medicare contractors can establish LCDs: they can decide to cover an item or service at the local level.

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[4] The healthcare sector of the U.S. economy is much more R&D-intensive then the economy as a whole. In 2020, estimated U.S. medical and health R&D investment was $245 billion (Research America (2022)), which was 5.9% of total U.S. health spending ($4154 billion) (CMS (2024)). In 2020, the ratio of U.S. R&D to GDP was 3.4% (National Center for Science and Engineering Statistics (2024)).

[5] 1999 is the first year in which the ICD-10-CM cause of death classification was used. To avoid the impact of the COVID-19 pandemic, our sample period ends in 2019.

[6] During the period 1999-2019, age-adjusted rates of the number of years of potential life lost before ages 85, 75, and 65 per 100,000 population declined by about 20%.

One component of the Medicare Coverage Database, the "Current and Retired Articles" database (CMS (2024c)), contains the complete set of the most current, in effect (or future effective) and retired, Local Coverage Article versions. This database contains 2.4 million links between HCPCS codes and covered disease (ICD-10-CM) codes. Appendix Table 4 provides an illustration of the data for a single disease, Salmonella sepsis (A02.1). Thirty-one HCPCS codes (listed in order of year of HCPCS code establishment) are covered in at least one LCD for that disease.[7]

We will construct two types of measures of innovation in HCPCS codes associated with a disease. The first measure is the long-run change in the *number* of HCPCS codes associated with the disease that had ever been established. As illustrated by Figure 2, the magnitude of this change varied considerably across diseases. From 1994 to 2019, the number of HCPCS codes associated with "malignant neoplasms of other and unspecified sites within the lip, oral cavity and pharynx" (C03-C09, C14.2-C14.8) increased by 66%, from 172 to 285, while the number of HCPCS codes associated with "infections with a predominately sexual mode of transmission: other and unspecified syphilis" (A50-A51, A52.7-A52.9, A53) increased by 132%, from 170 to 395.

The second measure is the long-run change in the *mean vintage* (year of HCPCS code establishment) of HCPCS codes associated with the disease that had ever been established.[8] Calculation of the two measures is illustrated in Appendix Table 5. Suppose that 2 HCPCS codes, established in 1998 and 2000, are associated with disease A, and that 2 HCPCS codes, established in 1998 and 2018, are associated with disease B. In both cases, the number of HCPCS codes ever established increased from 1 in 1999 to 2 in 2019. However, for disease A, the mean vintage of HCPCS codes ever established increased by only one year between 1999

[7] Unfortunately, it is not possible to construct similar data from National Coverage Determinations. However, Moneer et al (2014) noted that "local coverage determinations…represent the vast majority of Medicare's coverage decisions for new technologies." According to the Medicare Coverage Database (CMS (2024b)), as of 21 December 2024, there were 338 NCDs and 2324 LCDs. HCPCS listed in LCDs accounted for 67% of services provided and 73% of Medicare Part B expenditure in 2022.

[8] Some theoretical models postulate that economic growth depends on growth of the number of ideas. For example, Jones (2019, p. 861) said that "with nonrivalry, growth in income per person is tied to growth in the total stock of ideas." Other models postulate that growth depends on the growth of the vintage of technology or capital. As noted by Jovanovic and Yatsenko (2012), in "the Spence–Dixit–Stiglitz tradition…new goods [are] of higher quality than old goods." In 1987, when the Royal Swedish Academy of Sciences (1987) awarded the Nobel Prize in Economic Sciences to Robert Solow for his contributions to the theory of economic growth, it noted that "the most important aspect of Solow's article was not so much the empirical outcome, but the method of analyzing 'vintage capital'."

and 2019, while for disease B, the mean vintage of HCPCS codes ever established increased by ten years between 1999 and 2019.

In the next section, we present our econometric model of mortality. Data sources and descriptive statistics are presented in section III. Empirical results are presented in section IV. Implications of the estimates are discussed in section V. The final section provides a summary.

II. Econometric model of mortality

Our assessment of the impact that medical procedure and product innovations had on the mortality of Americans will be based on the following two-way fixed effects model:

$$\ln(\text{mortality}_{dt}) = \beta_k \, \text{hcpcs_measure}_{d,t-k} + \alpha_d + \delta_t + \varepsilon_{dt} \qquad (1)$$

where mortality_{dt} is one of the following variables:

ypll85_{dt} = the number of years of potential life lost before age 85 due to disease d in year t (t = 1999, 2000, 2001,…, 2019)

ypll75_{dt} = the number of years of potential life lost before age 75 due to disease d in year t

ypll65_{dt} = the number of years of potential life lost before age 65 due to disease d in year t[9]

age_death_{dt} = the mean age at death from disease d in year t

n_deaths_{dt} = the number of deaths from disease d in year t

and $\text{hcpcs_measure}_{d,t-k}$ is one of the following variables:

$\ln(\text{n_hcpcs}_{d,t-k})$ = the log of the number of procedures used to treat disease d whose codes were established by year t-k (k = 0, 1, 2,…, 8)

$\text{vint_hcpcs}_{d,t-k}$ = the mean vintage (year of code establishment) of procedures used to treat disease d whose codes were established by year t-k

[9] The U.S. CDC's WISQARS Years of Potential Life Lost (YPLL) Report website permits one to specify age thresholds of 65, 70, 75, 80, and 85. The World Health Organization has used YPLL to measure disease burden in its Global Burden of Disease (GBD) and Global Health Estimates (GHE) reports for many years. In the 2010 GBD, the WHO used an age threshold of 86.01 years for all persons. In the current GHE, the WHO uses an age threshold of 91.93 years for all persons.

$n_hcpcs_{d,t-k}$ is calculated as follows:

$n_hcpcs_{d,t-k} = \sum_h covered_{hd}\ established_{h,t-k}$

where

$covered_{hd}$ = 1 if HCPCS code h is covered for disease d in at least 1 LCD
= 0 if HCPCS code h is not covered for disease d in at least 1 LCD

$established_{h,t-k}$ = 1 if HCPCS code h was established by year t-k
= 0 if HCPCS code h was not established by year t-k

$vint_hcpcs_{d,t-k}$ is calculated as follows:

$vint_hcpcs_{d,t-k} = (\sum_h covered_{hd}\ established_{h,t-k}\ hcpcs_year_h) / (\sum_h covered_{hd}\ established_{h,t-k})$

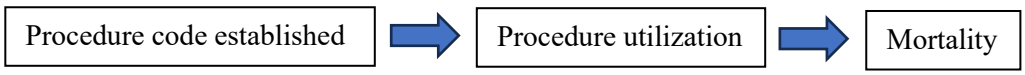
where

$hcpcs_year_h$ = the year in which HCPCS code h was established

In eq. (1), α_d is a fixed effect for disease d, and δ_t is a fixed effect for year t. The year fixed effects (δ_t's) in eq. (1) control for the effects of changes in aggregate demographic and macroeconomic variables (e.g. population size and age structure, GDP, educational attainment), to the extent that those variables have similar effects on mortality from different diseases.

Eq. (1) will be estimated by weighted least-squares. When $mortality_{dt} \neq age_death_{dt}$, the weight will be $\sum_t mortality_{dt}$. When $mortality_{dt} = age_death_{dt}$, the weight will be n_deaths_{dt}. Disturbances will be clustered within diseases.

Eq. (1) allows the effect on mortality of the number or vintage of procedures ever established to be subject to a lag. There may be a lag for two reasons, which may be depicted as follows:



First, peak utilization of a procedure may occur years after the code for the procedure was established. We can obtain some evidence about the shape of the typical procedure "age-utilization profile"—the relationship between time since procedure code establishment and procedure utilization—using annual 2013-2022 CMS data on "Medicare Physician & Other

Practitioners - by Geography and Service." Figure 3 shows the mean number of times each procedure was used, by age (number of years after code establishment) of procedure. Surprisingly, mean utilization of procedures is about half a million in the year that the code was established (and in each of the following 2 years). It rises to 700,000 by age 5 and then starts to decline.

A potential explanation for this is that the establishment of a HCPCS code may be a "lagging indicator": procedures may be used years before they are assigned HCPCS codes. For one important type of procedure—provider-administered drugs—we have evidence to support this hypothesis. Medicare contractors (e.g., Palmetto GBA (2024)) publish "NDC/HCPCS Crosswalks": listings of each National Drug Code (NDC) that is assigned to a HCPCS. From the Medical Expenditure Panel Survey (MEPS) Prescribed Medicine Files (Agency for Healthcare Research and Quality (2024)), we can obtain estimates of the number of prescriptions by NDC and year during the period 1996-2022. Our calculations reveal that 16% of MEPS prescriptions for NDCs linked to HCPCS codes were consumed in years prior to the year the HCPCS code was established. This provides support for the hypothesis that procedures may be used years before they are assigned HCPCS codes.

The diseases identified in the LCDs are extremely detailed; 27,444 distinct diseases (e.g., D72.822 Plasmacytosis) are identified. The diseases identified in the mortality data are less detailed; 3914 distinct ICD-10-CM causes of death are identified in the 2019 mortality data. We will use the CDC's 358 cause of death classification (Centers for Disease Control and Prevention (2024; page 24)) to aggregate the data and perform the analysis. External causes of mortality (*U01-*U03, V01-Y89) are excluded.

III. Data sources

HCPCS data. Data on $covered_{hd}$ (which indicates whether HCPCS code h is covered for disease d in at least 1 local coverage determination) were obtained from CMS' Current and Retired Articles database, which contains data on the most current, in effect (or future effective), and retired, Local Coverage Article versions. Data on $hcpcs_year_h$ (the year in which HCPCS code h was established) were obtained from the Restructured BETOS Classification System database (HealthData.gov (2024)). Data on the number of services and Medicare expenditure, by

HCPCS code and year (2013-2022), were obtained from the Medicare Physician & Other Practitioners - by Geography and Service database (CMS (2024)).

Mortality Data were obtained from annual 1999-2019 Multiple Cause-of-Death Mortality files derived from the National Vital Statistics System of the National Center for Health Statistics. These files may be downloaded from the National Bureau of Economic Research website. Each record in the microdata is based on information abstracted from death certificates filed in vital statistics offices of each State and District of Columbia. Causes of death were coded according to the International Classification of Diseases, Tenth Revision from 1999 on. Each record contains the 358 cause recode of the underlying cause of death, the decedent's age at time of death, educational attainment, and race.

Appendix Table 6 displays 1999 and 2019 mortality and HCPCS data for the top 38 diseases, ranked by number of deaths during 1999-2019.

IV. Empirical results

Estimates of eq. (1) when $hcpcs_measure_{d,t-k} = \ln(n_hcpcs_{d,t-k})$ for different mortality measures are reported in Appendix Table 7. Estimates of eq. (1) when $hcpcs_measure_{d,t-k} = vint_hcpcs_{d,t-k}$ for different mortality measures are reported in Table 1 and plotted in Figure 4. The estimates based on the two alternative innovation measures are qualitatively similar, but mortality is more strongly related to the mean vintage of HCPCS codes ever established than it is to the number of HCPCS codes ever established, so henceforth we will focus on estimates of eq. (1) when $hcpcs_measure_{d,t-k} = vint_hcpcs_{d,t-k}$.

In panel A of Table 1 and Figure 4, the dependent variable is $\ln(ypll85_{dt})$: the log of the number of years of potential life lost before age 85 due to disease d in year t. $\ln(ypll85_{dt})$ is significantly inversely related to the mean vintage of HCPCS codes ever established 0 to 4 years earlier. It is most strongly inversely related to the mean vintage of HCPCS codes ever established one year earlier. The point estimate of β_1 indicates that a one-year increase in HCPCS vintage reduces premature (before age 85) mortality one year later by 1.4%. Between 1999 and 2019, the weighted (by $ypll85_{dt}$) mean value of $vint_hcpcs_{d,t-1}$ increased by 10.6 years (from 1987.4 to 1998.0). This implies that the 1998-2018 increase in vintage reduced premature (before age 85) mortality by 14.6% (= .0138 * 10.6). During the period 1999-2019, the age-

adjusted rate of the number of years of potential life lost before age 85 per 100,000 population declined by about 20%.

In panel B of Table 1 and Figure 4, the dependent variable is $\ln(ypll75_{dt})$: the log of the number of years of potential life lost before age 75 due to disease d in year t. $\ln(ypll75_{dt})$ is significantly inversely related to the mean vintage of HCPCS codes ever established 0 to 6 years earlier. It is most strongly inversely related to the mean vintage of HCPCS codes ever established three years earlier. The point estimate of β_3 indicates that a one-year increase in HCPCS vintage reduced premature (before age 75) mortality three years later by 1.7%.

In panel C of Table 1 and Figure 4, the dependent variable is $\ln(ypll65_{dt})$: the log of the number of years of potential life lost before age 65 due to disease d in year t. $\ln(ypll65_{dt})$ is significantly inversely related to the mean vintage of HCPCS codes ever established 0 to 6 years earlier. It is most strongly inversely related to the mean vintage of HCPCS codes ever established three years earlier. The point estimate of β_3 indicates that a one-year increase in HCPCS vintage reduced premature (before age 65) mortality three years later by 1.8%.

In panel D of Table 1 and Figure 4, the dependent variable is $\ln(age_death_{dt})$: the log of the mean age at death from disease d in year t. $\ln(age_death_{dt})$ is significantly positively related to the mean vintage of HCPCS codes ever established 2 to 8 years earlier. It is most strongly related to the mean vintage of HCPCS codes ever established five years earlier. The point estimate of β_5 indicates that a one-year increase in HCPCS vintage increased mean age at death five years later by 0.23%. During the period 1999-2019, mean age at death increased by 1.38%.

In panel E of Table 1, the dependent variable is $\ln(n_deaths_{dt})$: the log of the number of deaths from disease d in year t. $\ln(n_deaths_{dt})$ is not significantly related to the mean vintage of HCPCS codes ever established in year t or any of the previous 8 years. The innovation-induced reductions in the number of years of potential life lost before ages 85, 75, and 65 appear to be due to an increase in mean age at death from the disease rather than to a reduction in the number of deaths from the disease.

As noted above, we can assess the impact that innovation had on the mortality of different demographic groups, defined by education or race, by estimating eq. (1) using group-specific mortality data. Estimates of eq. (1) when $hcpcs_measure_{d,t-k} = vint_hcpcs_{d,t-k}$, by educational attainment of the decedent, are shown in Table 2 and plotted in Figure 5. Educational attainment is divided into three categories: 0-11 years, 12 years, and 13+ years of

education. The left side of Table 2 (panels A, B, and C), and the top of Figure 5 (panel A), show the estimates when $mortality_{dt} = ypll75_{dt}$. For all three education groups, $\ln(ypll75_{dt})$ is significantly inversely related to the mean vintage of HCPCS codes ever established 0 to 5 years earlier. This indicates that premature (before age 75) mortality of all education groups was reduced by medical innovation. Surprisingly, medical innovation appears to have had a larger (more negative) impact on the mortality of people with 12 years of education than it had on the mortality of people with either less or more education, although the estimated differences may not be statistically significant.

The right side of Table 2 (panels D, E, and F), and the bottom of Figure 5 (panel B), show the estimates by education group when $mortality_{dt} = age_death_{dt}$. Mean age at death of people with 12 or 13+ years of education is significantly positively related to the mean vintage of HCPCS codes ever established 0-8 years earlier, but mean age at death of people with 0-11 years of education is only significantly positively related to the mean vintage of HCPCS codes ever established 7-8 years earlier. This may indicate that innovation increases the longevity of more educated people sooner than it increases the longevity of less educated people, perhaps because more educated people have earlier access to innovations. However, innovation appears to have similar long-run (after 7 or 8 years) effects on the longevity of the three education groups.

To assess whether innovation had different effects on the mortality of different racial groups, we also estimated eq. (1) using only black mortality data. These estimates are shown in Appendix Table 8. $vint_hcpcs_{d,t-k}$ did not have a significant effect on any of the three premature mortality measures ($\ln(ypll85_{dt})$, $\ln(ypll75_{dt})$, $\ln(ypll65_{dt})$) for any value of k. The standard errors of the estimates in Table 1 and Appendix Table 8 are quite similar, so the insignificance of the estimates in Panels A, B, and C of Appendix Table 8 does not appear to be due to greater volatility of the black mortality data. Mean age at death of blacks is significantly positively related to the mean vintage of HCPCS codes ever established 5-8 years earlier. The estimates may indicate that innovation increased the longevity of black people later than it increased the longevity of other racial groups, perhaps because black people had later access to innovations. However, the long-run (after 5-8 years) effect of innovation on the longevity of black people appears to be similar to its effects on the longevity of other racial groups.

V. Discussion

Estimates of two versions of eq. (1)—including and excluding $hcpcs_measure_{d,t-k}$ as a regressor—enable us to estimate how much biomedical innovation reduced mortality during the period 1999-2019. When $hcpcs_measure_{d,t-k}$ is included in eq. (1), δ_{2019} is an estimate of the 1999-2019 change in mortality, holding constant $hcpcs_measure_{d,t-k}$, i.e., in the *absence* of biomedical innovation. (δ_{1999} is normalized to zero.) When $hcpcs_measure_{d,t-k}$ is excluded from eq. (1), δ_{2019} is an estimate of the 1999-2019 change in mortality in the *presence* of biomedical innovation. Changes in age-adjusted mortality *rates* can be computed by subtracting the corresponding log-change in age-adjusted population from the δ_{2019} estimates.

These calculations are shown for four mortality measures (when $hcpcs_measure_{d,t-k} = vint_hcpcs_{d,t-k}$) in Figure 6. In each case, we use the lag for which the relationship is most significant. Panel A shows estimates of the post-1999 log change in the age-adjusted ypll85 rate in the presence and absence of the change in vint_hcpcs one year earlier. The growth (log-change) in the presence of biomedical innovation is -0.20 and is significantly different from zero. The growth in the absence of biomedical innovation is -0.05 and is not significantly different from zero. We cannot reject the null hypothesis that in the absence of biomedical innovation, as measured by the lagged change in vint_hcpcs, the age-adjusted ypll85 rate would not have declined during the period 1999-2019. The estimates for the age-adjusted ypll75 and ypll65 rates in Panels B and C are quite similar. As shown in Panel D, mean age at death was 0.98% higher in 2019 than it was in 1999 (controlling for disease fixed effects), and this increase was statistically significant. Our estimates indicate that, if vint_hcpcs had not increased between 1994 and 2014, mean age at death would have been 1.23% *lower* in 2019 than it was in 1999, although this estimated decline is not statistically significantly different from zero.

Some factors other than biomedical innovation probably contributed to the decline in mortality. The adult cigarette smoking rate declined from 23.5% in 1999 to 13.7% in 2018 (American Lung Association (2024)). The fraction of adults who had at least a bachelor's degree increased from 23.9% in 1997 to 34.2% in 2017 (American Council on Eduction (2024)). However, other factors probably contributed to an increase in mortality. From 1999-2000 through 2017-March 2020, US obesity prevalence increased from 30.5% to 41.9%, and the prevalence of severe obesity increased from 4.7% to 9.2%. Obesity-related

conditions include heart disease, stroke, type 2 diabetes and certain types of cancer. These are among the leading causes of preventable, premature death (Centers for Disease Control (2024)). And between 2007 and 2018, the prevalence of 14 out of 21 chronic conditions among male Medicare beneficiaries increased, and the prevalence of 16 out of 21 chronic conditions among female beneficiaries increased (Center for Medicare and Medicaid Services (2024)).

VI. Summary and conclusions

During the last 40 years, there have been many innovations in medical services, supplies, and equipment: the number of Healthcare Common Procedure Coding System (HCPCS) codes ever established increased from 4994 in 1984 to 17,997 in 2023. We assessed the impact that those innovations had on the mortality of Americans during the period 1999-2019 using a difference-in-differences research design: we investigated whether the diseases that were subject to more innovation exhibited larger declines in mortality. We used Medicare Coverage Determinations data to determine which disease(s) each HCPCS code is associated with. All the data used are publicly available on the internet.

We constructed two types of measures of innovation associated with a disease: the long-run change in the *number* of HCPCS codes associated with the disease that had ever been established, and the long-run change in the *mean vintage* (year of HCPCS code establishment) of HCPCS codes associated with the disease that had ever been established. The estimates based on the two alternative innovation measures are qualitatively similar, but mortality is more strongly related to the mean vintage of HCPCS codes ever established than it is to the number of HCPCS codes ever established.

Our estimates indicated that the number of years of potential life lost before ages 85, 75, and 65 from a disease is significantly inversely related to the mean vintage of HCPCS codes associated with the disease that had ever been established 0-4 or 0-6 years earlier. Mean age at death from a disease is significantly positively related to the mean vintage of HCPCS codes associated with the disease that had ever been established 2-8 years earlier. The number of deaths from a disease is *not* significantly related to the mean vintage of HCPCS codes associated with the disease that had ever been established 0-8 years earlier.

In addition to assessing the impact that those innovations had on the mortality of all Americans, we assessed the impact that they had on the mortality of different demographic groups, defined by education or race. Premature (before age 75) mortality of all education groups (people with 0-11 years, 12 years, or 13+ years of education) was reduced by medical innovation. Innovation may have increased the longevity of more educated people sooner than it increased the longevity of less educated people, perhaps because more educated people have earlier access to innovations, but innovation appears to have had similar long-run (after 7 or 8 years) effects on the longevity of the three education groups.

Premature (before ages 85, 75, and 65) mortality rates of Black Americans is not significantly related to the mean vintage of HCPCS codes that had ever been established 0-8 years earlier, but their mean age at death is significantly positively related to the mean vintage of HCPCS codes that had ever established 5-8 years earlier. Innovation may have increased the longevity of black people later than it increased the longevity of other racial groups, perhaps because black people had later access to innovations, but the long-run (after 5-8 years) effect of innovation on the longevity of black people appears to be similar to its effects on the longevity of other racial groups.

During the period 1999-2019, age-adjusted rates of premature (before ages 85, 75, and 65) mortality declined by about 20%. We cannot reject the null hypothesis that in the absence of biomedical innovation, the premature mortality rates would not have declined during the period 1999-2019. Some factors other than biomedical innovation (e.g., the decline in smoking rates and the increase in educational attainment) probably contributed to the decline in mortality. However, other factors (the increase in obesity and chronic condition prevalence) probably contributed to an increase in mortality.

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Table 1

Estimates of β_k from model $\ln(mortality_{dt}) = \beta_k\ vint_hcpcs_{d,t-k} + \alpha_d + \delta_t + \varepsilon_{dt}$

k (lag)	Estimate	Std. Err.	Z	Pr > |Z|		k (lag)	Estimate	Std. Err.	Z	Pr > |Z|
	A. $mortality_{dt} = yll85_{dt}$						B. $mortality_{dt} = yll75_{dt}$			
0	**-0.0132**	**0.0058**	**-2.26**	**0.0238**		0	**-0.0152**	**0.0058**	**-2.64**	**0.0083**
1	**-0.0138**	**0.0060**	**-2.30**	**0.0216**		1	**-0.0161**	**0.0059**	**-2.71**	**0.0067**
2	**-0.0139**	**0.0062**	**-2.26**	**0.0241**		2	**-0.0167**	**0.0061**	**-2.73**	**0.0064**
3	**-0.0139**	**0.0063**	**-2.22**	**0.0261**		3	**-0.0172**	**0.0062**	**-2.76**	**0.0058**
4	**-0.0132**	**0.0065**	**-2.05**	**0.0407**		4	**-0.0170**	**0.0064**	**-2.66**	**0.0079**
5	-0.0118	0.0068	-1.73	0.0829		5	**-0.0163**	**0.0067**	**-2.42**	**0.0154**
6	-0.0097	0.0074	-1.32	0.1868		6	**-0.0148**	**0.0073**	**-2.02**	**0.0435**
7	-0.0069	0.0087	-0.80	0.4256		7	-0.0131	0.0086	-1.52	0.1280
8	-0.0070	0.0115	-0.61	0.5443		8	-0.0144	0.0113	-1.28	0.2000
	C. $mortality_{dt} = yll65_{dt}$						D. $mortality_{dt} = age_death_{dt}$			
0	**-0.0155**	**0.0053**	**-2.95**	**0.0032**		0	0.0016	0.0008	1.89	0.0583
1	**-0.0166**	**0.0054**	**-3.07**	**0.0021**		1	0.0017	0.0009	1.95	0.0511
2	**-0.0176**	**0.0056**	**-3.13**	**0.0018**		2	**0.0018**	**0.0009**	**2.05**	**0.0400**
3	**-0.0184**	**0.0058**	**-3.16**	**0.0016**		3	**0.0019**	**0.0009**	**2.16**	**0.0306**
4	**-0.0184**	**0.0062**	**-3.00**	**0.0027**		4	**0.0021**	**0.0010**	**2.21**	**0.0272**
5	**-0.0182**	**0.0067**	**-2.71**	**0.0067**		5	**0.0023**	**0.0011**	**2.22**	**0.0263**
6	**-0.0167**	**0.0077**	**-2.18**	**0.0294**		6	**0.0025**	**0.0012**	**2.09**	**0.0363**
7	-0.0151	0.0091	-1.67	0.0955		7	**0.0029**	**0.0014**	**2.04**	**0.0411**
8	-0.0160	0.0121	-1.32	0.1885		8	**0.0038**	**0.0018**	**2.09**	**0.0367**
	E. $mortality_{dt} = n_deaths_{dt}$									
0	-0.0096	0.0088	-1.09	0.2777						
1	-0.0084	0.0087	-0.97	0.3331						
2	-0.0060	0.0087	-0.68	0.4945						
3	-0.0033	0.0094	-0.35	0.7228						
4	0.0011	0.0109	0.10	0.9170						
5	0.0070	0.0132	0.53	0.5953						
6	0.0131	0.0156	0.84	0.4025						
7	0.0229	0.0195	1.17	0.2400						
8	0.0328	0.0259	1.26	0.2060						

Each estimate is from a separate model.

Estimates in bold are statistically significant (p-value < .05).

Table 2

MORTALITY BY EDUCATIONAL ATTAINMENT

Estimates of β_k from model $\ln(\text{mortality}_{dt}) = \beta_k \text{ vint_hcpcs}_{d,t-k} + \alpha_d + \delta_t + \varepsilon_{dt}$

k (lag)	Estimate	Std. Err.	Z	Pr > |Z|		k (lag)	Estimate	Std. Err.	Z	Pr > |Z|
	0-11 years of education									
	A. mortality$_{dt}$ = yll75$_{dt}$						**D. mortality$_{dt}$ = age_death$_{dt}$**			
0	**-0.0159**	**0.0056**	**-2.83**	**0.0046**		0	0.0012	0.0009	1.36	0.1724
1	**-0.0165**	**0.0058**	**-2.83**	**0.0047**		1	0.0013	0.0009	1.37	0.1698
2	**-0.0171**	**0.0060**	**-2.83**	**0.0046**		2	0.0014	0.0010	1.46	0.1436
3	**-0.0175**	**0.0062**	**-2.83**	**0.0046**		3	0.0016	0.0010	1.61	0.1081
4	**-0.0172**	**0.0063**	**-2.72**	**0.0066**		4	0.0019	0.0011	1.76	0.0782
5	**-0.0168**	**0.0067**	**-2.53**	**0.0113**		5	0.0023	0.0012	1.95	0.0509
6	**-0.0152**	**0.0072**	**-2.11**	**0.0346**		6	0.0026	0.0013	1.95	0.0513
7	-0.0128	0.0082	-1.57	0.1164		7	**0.0030**	**0.0015**	**2.00**	**0.0454**
8	-0.0138	0.0103	-1.34	0.1808		8	**0.0041**	**0.0017**	**2.33**	**0.0198**
	12 years of education									
	B. mortality$_{dt}$ = yll75$_{dt}$						**E. mortality$_{dt}$ = age_death$_{dt}$**			
0	**-0.0229**	**0.0069**	**-3.29**	**0.0010**		0	**0.0016**	**0.0008**	**2.08**	**0.0372**
1	**-0.0238**	**0.0072**	**-3.31**	**0.0009**		1	**0.0017**	**0.0008**	**2.15**	**0.0318**
2	**-0.0243**	**0.0074**	**-3.28**	**0.0010**		2	**0.0018**	**0.0008**	**2.24**	**0.0252**
3	**-0.0245**	**0.0075**	**-3.28**	**0.0010**		3	**0.0019**	**0.0008**	**2.34**	**0.0190**
4	**-0.0240**	**0.0077**	**-3.12**	**0.0018**		4	**0.0020**	**0.0009**	**2.38**	**0.0175**
5	**-0.0229**	**0.0080**	**-2.88**	**0.0040**		5	**0.0022**	**0.0009**	**2.39**	**0.0170**
6	**-0.0208**	**0.0084**	**-2.47**	**0.0134**		6	**0.0024**	**0.0011**	**2.20**	**0.0281**
7	-0.0185	0.0096	-1.93	0.0534		7	**0.0027**	**0.0013**	**2.15**	**0.0318**
8	-0.0189	0.0123	-1.54	0.1241		8	**0.0035**	**0.0016**	**2.22**	**0.0262**
	13+ years of education									
	C. mortality$_{dt}$ = yll75$_{dt}$						**F. mortality$_{dt}$ = age_death$_{dt}$**			
0	**-0.0147**	**0.0056**	**-2.62**	**0.0087**		0	**0.0020**	**0.0007**	**2.85**	**0.0044**
1	**-0.0153**	**0.0058**	**-2.63**	**0.0086**		1	**0.0021**	**0.0007**	**2.94**	**0.0033**
2	**-0.0158**	**0.0061**	**-2.60**	**0.0094**		2	**0.0022**	**0.0007**	**3.05**	**0.0023**
3	**-0.0160**	**0.0062**	**-2.58**	**0.0099**		3	**0.0023**	**0.0007**	**3.17**	**0.0015**
4	**-0.0157**	**0.0065**	**-2.41**	**0.0160**		4	**0.0024**	**0.0008**	**3.15**	**0.0016**
5	**-0.0147**	**0.0070**	**-2.11**	**0.0352**		5	**0.0025**	**0.0008**	**3.02**	**0.0025**
6	-0.0131	0.0077	-1.69	0.0908		6	**0.0026**	**0.0009**	**2.80**	**0.0052**
7	-0.0111	0.0091	-1.22	0.2223		7	**0.0030**	**0.0011**	**2.64**	**0.0082**
8	-0.0115	0.0126	-0.91	0.3612		8	**0.0038**	**0.0016**	**2.39**	**0.0170**

Each estimate is from a separate model.

Estimates in bold are statistically significant (p-value < .05).

Figure 1
Number of HCPCS codes ever established, 1984-2023

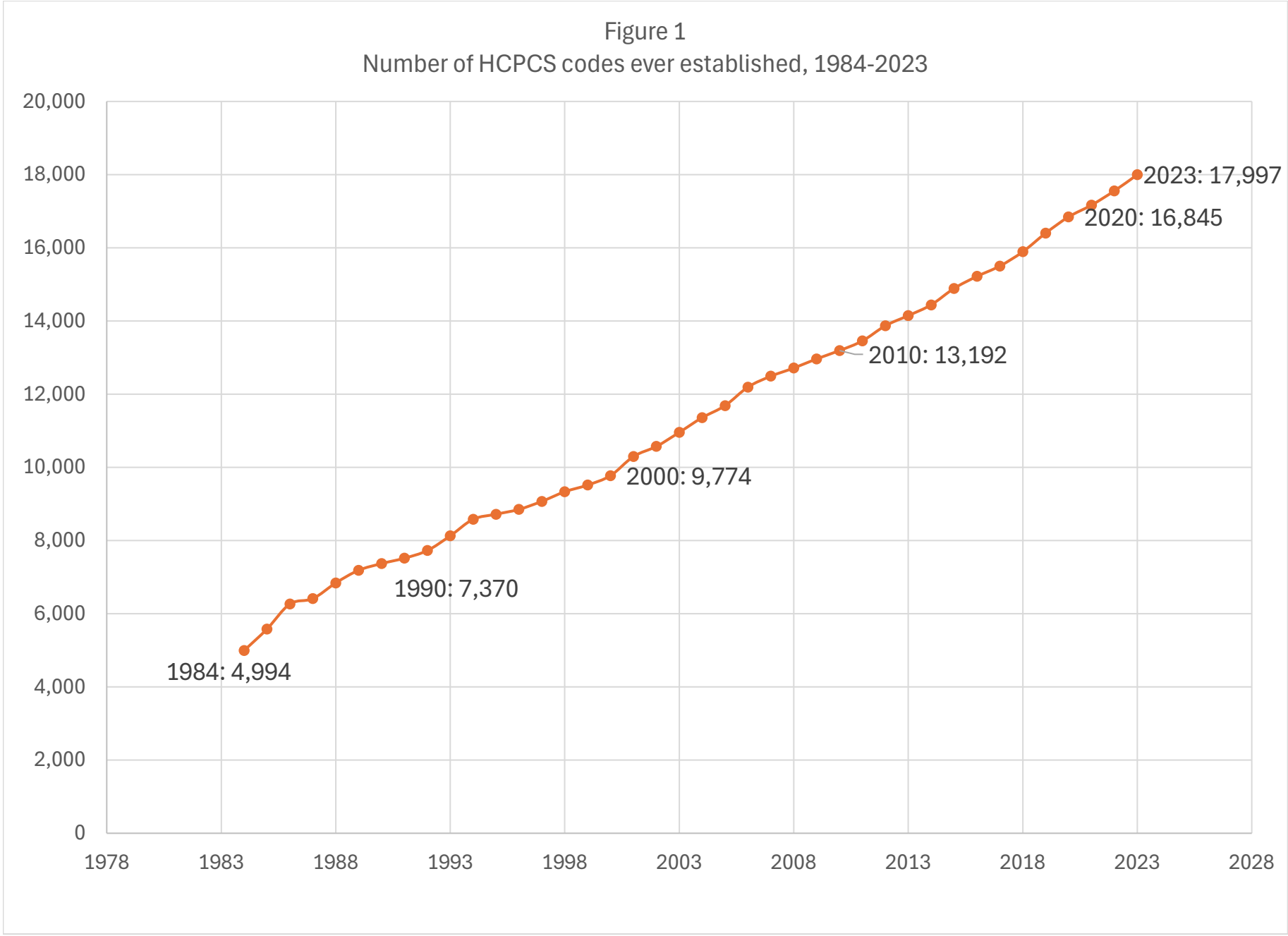


Figure 2

Number of HCPCS codes associated with five diseases ever established, 1994-2019

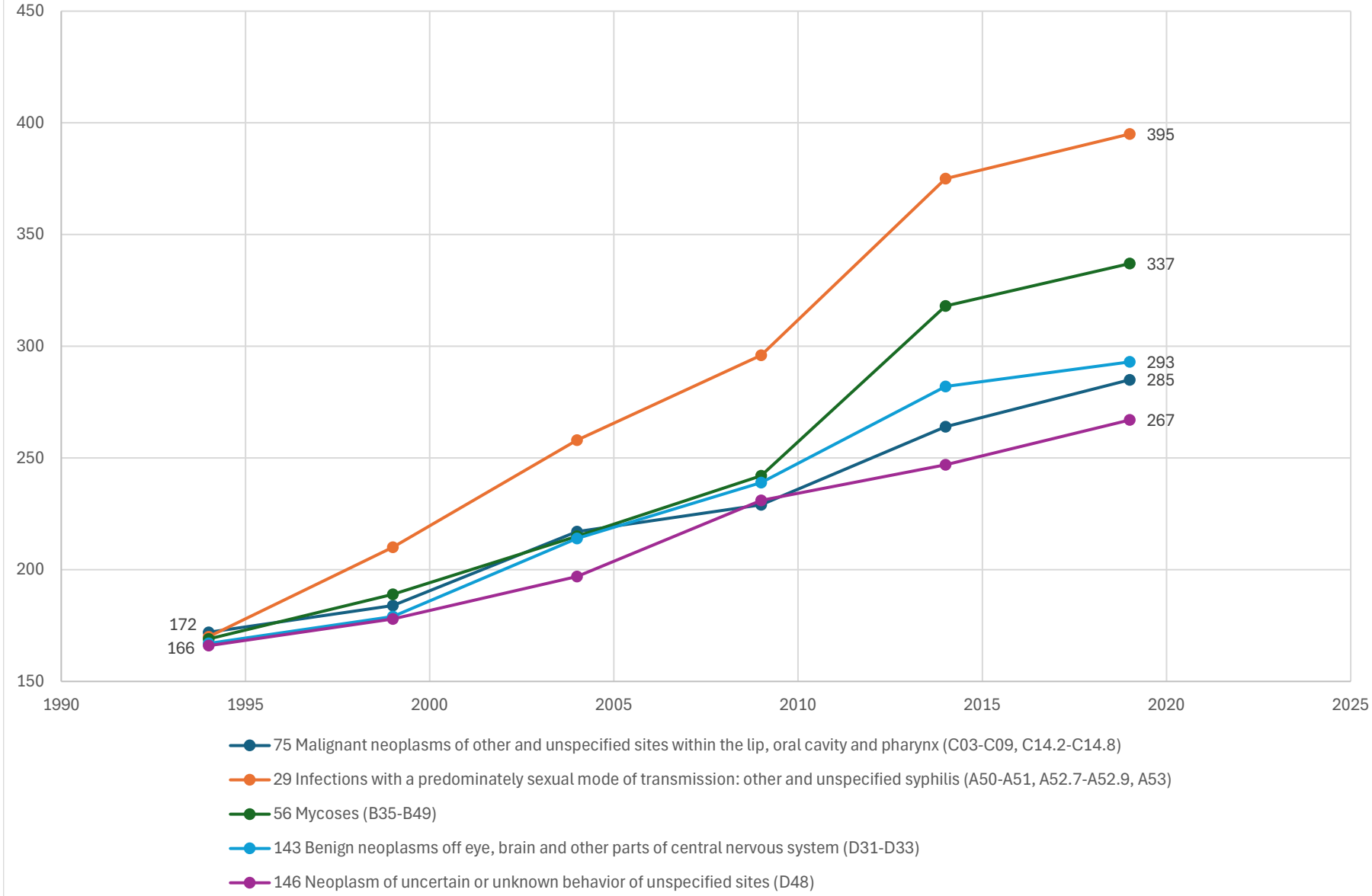


Figure 3
Mean number of times each procedure was used,
by age (number of years after code establishment) of procedure

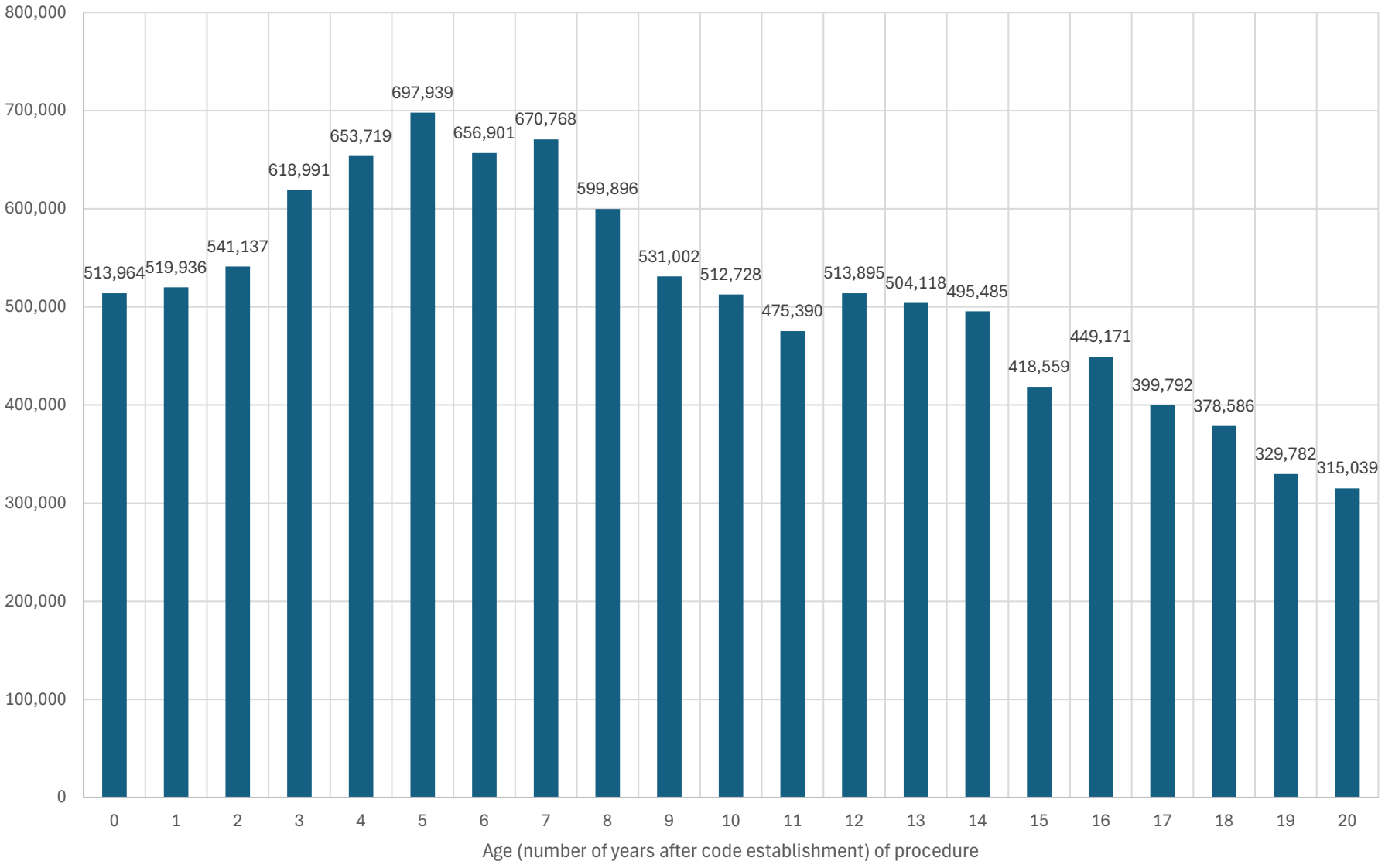
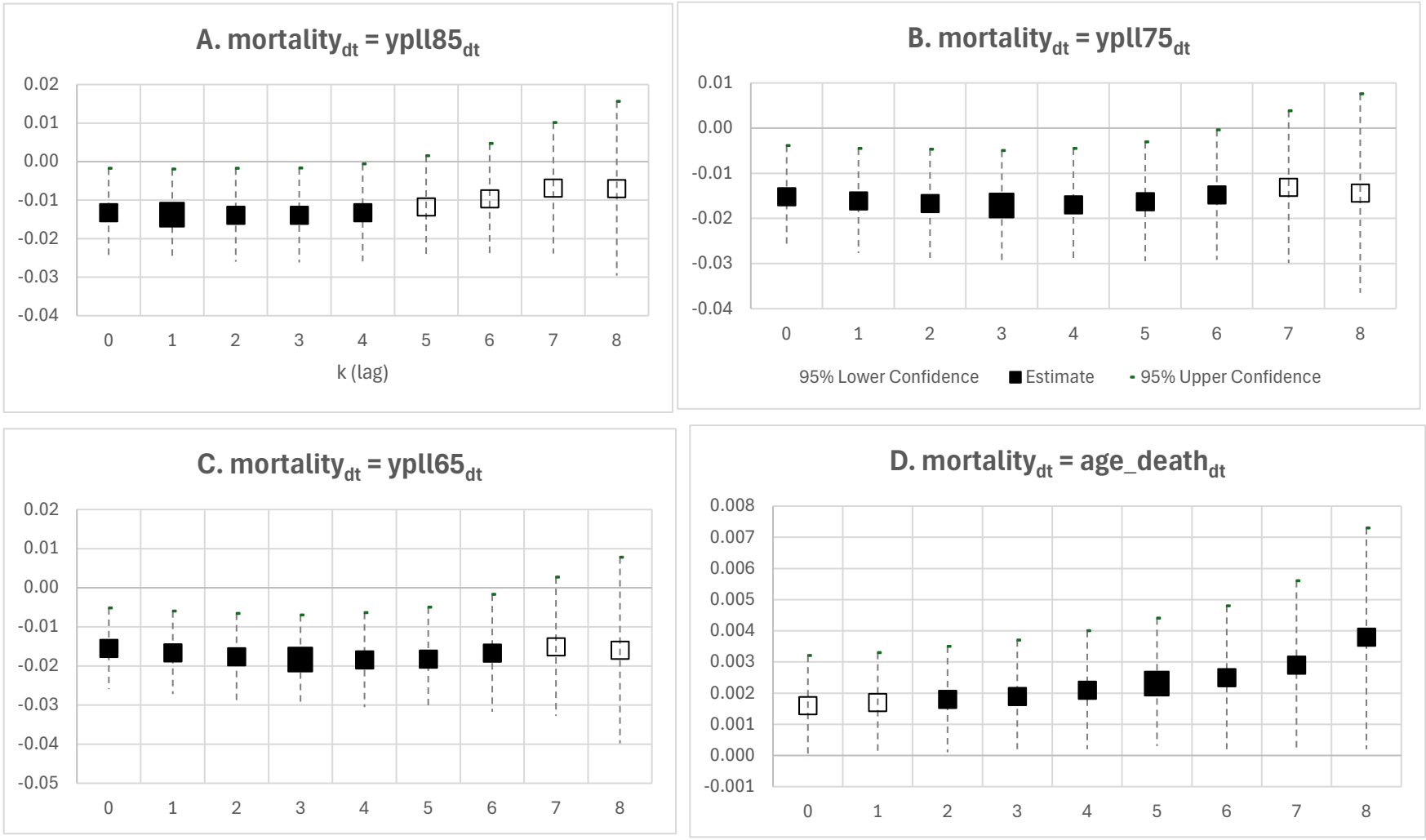


Figure 4

Estimates of β_k from model $\ln(mortality_{dt}) = \beta_k\, vint_hcpcs_{d,t-k} + \alpha_d + \delta_t + \varepsilon_{dt}$



A solid marker indicates a statistically significant (p-value < .05) estimate.

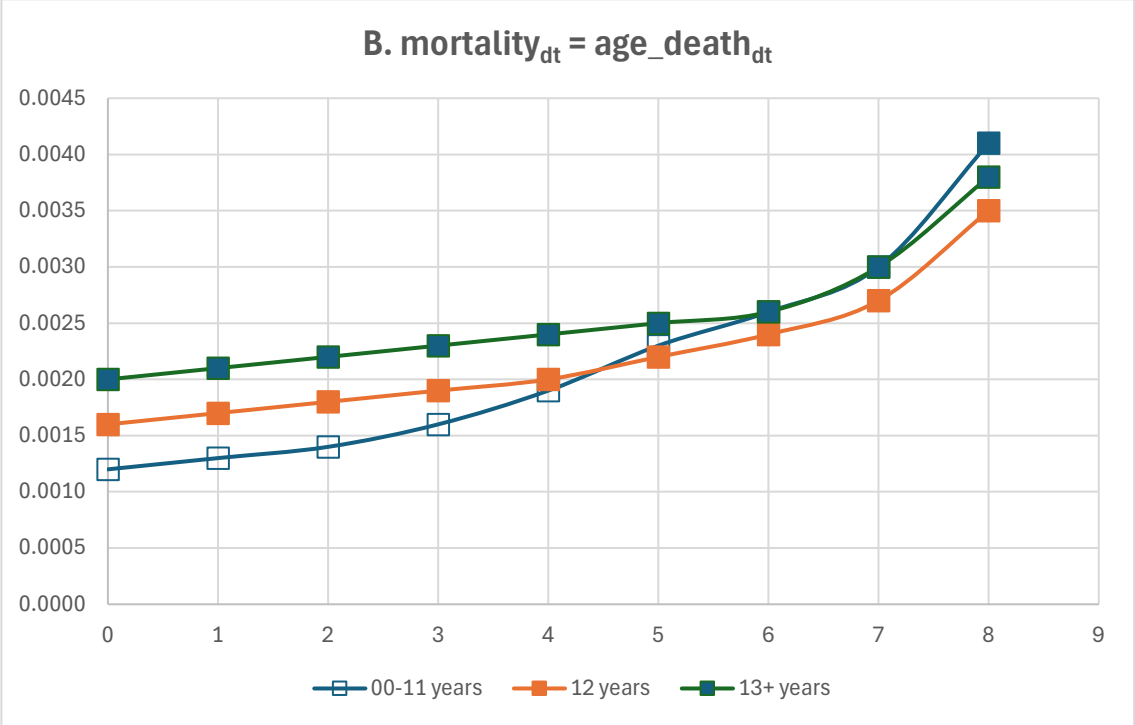
A hollow marker indicates a statistically insignificant estimate.

Figure 5

MORTALITY BY EDUCATIONAL ATTAINMENT

Estimates of β_k from model $\ln(mortality_{dt}) = \beta_k\ vint_hcpcs_{d,t-k} + \alpha_d + \delta_t + \varepsilon_{dt}$

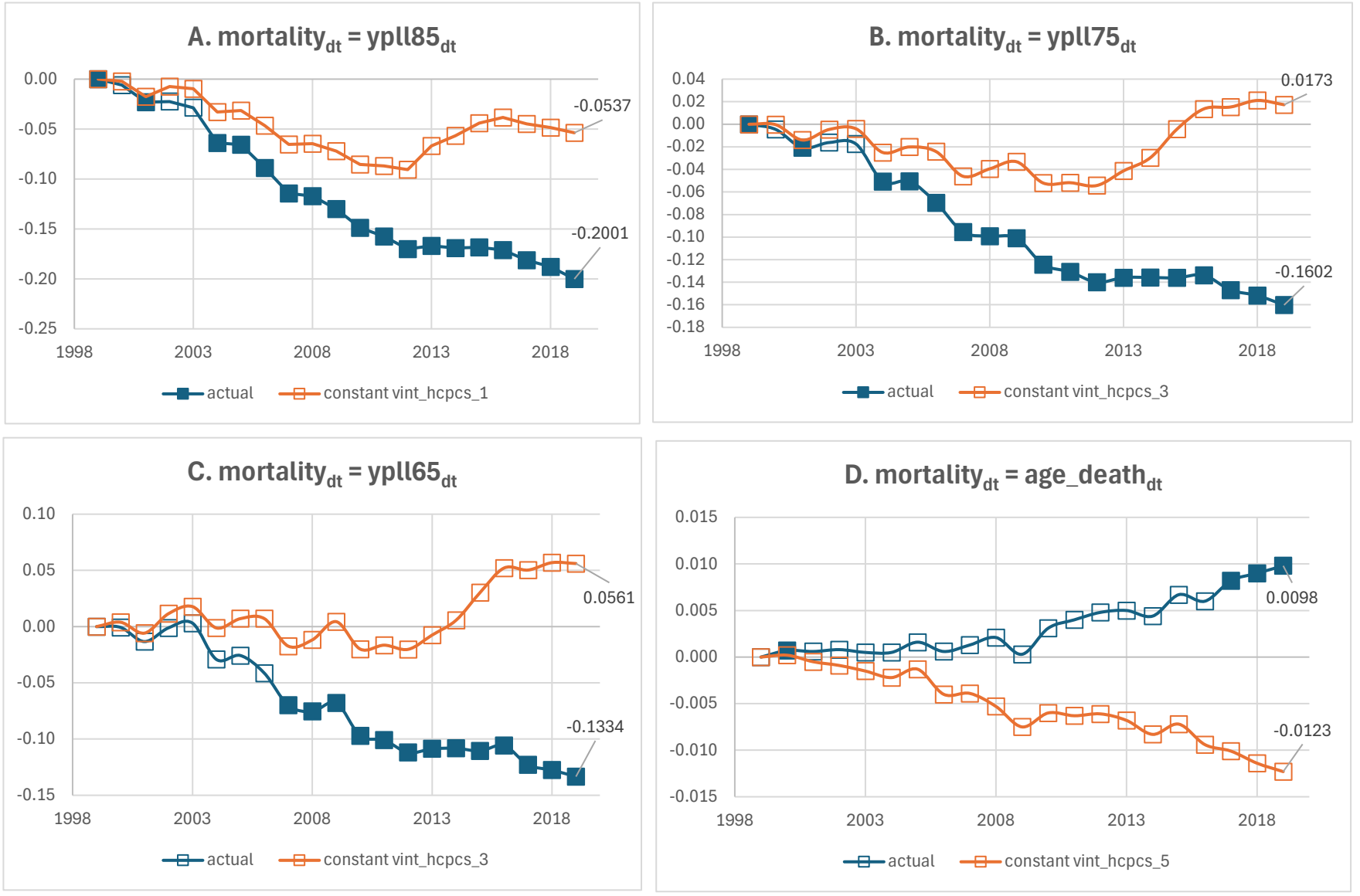




A solid marker indicates a statistically significant (p-value < .05) estimate.
A hollow marker indicates a statistically insignificant estimate.

Figure 6

Actual versus counterfactual (constant lagged vint_hcpcs) post-1999 change in mortality, 2000-2019



A solid marker indicates that the value in year t is significantly different (p-value < .05) from the 1999 value.

A hollow marker indicates that the value in year t is not significantly different from the 1999 value.

Appendix Table 1

No. of HCPCS codes ever established by end of 2023, by RBCS Category/subcategory

RBCS Category/subcategory	No. of HCPCS codes, end of 2023
Anesthesia	**308**
Anesthesia	308
DME	**3196**
Drugs Administered Through DME	81
Hospital Beds	37
Medical/Surgical Supplies	691
Orthotic Devices	1264
Other DME	616
Oxygen and Supplies	25
Wheelchairs	482
E&M	**717**
Behavioral Health Services	153
Care Management/Coordination	104
Critical Care Services	20
E&M - Miscellaneous	108
Emergency Department Services	19
Home Services	47
Hospice	9
Hospital Inpatient Services	33
Nursing Facility Services	29
Observation Care Services	12
Office/Outpatient Services	136
Ophthalmological Services	47
Imaging	**1136**
CT Scan	131
Imaging - Miscellaneous	41
Magnetic Resonance	111
Nuclear	249
Standard X-ray	445
Ultrasound	159
Other	**234**
Ambulance	21
Enteral and Parenteral	49
Vision, Hearing, and Speech Services	164
Procedure	**7294**
Breast	85
Cardiovascular	650
Digestive/Gastrointestinal	1012
Eye	361
Hematology	70

Appendix Table 1

No. of HCPCS codes ever established by end of 2023, by RBCS Category/subcategory

RBCS Category/subcategory	No. of HCPCS codes, end of 2023
Musculoskeletal	2206
Other Organ Systems	1948
Skin	475
Vascular	487
Test	**3128**
Anatomic Pathology	147
Cardiography	120
General Laboratory	1368
Molecular Testing	1071
Neurologic	150
Pulmonary	49
Pulmonary Function	43
Test - Miscellaneous	180
Treatment	**1984**
Chemotherapy	341
Dialysis	123
Injections and Infusions (nononcologic)	1088
Physical, Occupational, and Speech Therapy	76
Radiation Oncology	173
Spinal Manipulation	9
Treatment - Miscellaneous	174
Grand Total	**17997**

Appendix Table 2

Number of HCPCS codes ever established by 2000 and 2023, by Restructured BETOS Classification System category

Restructured BETOS Classification System category	2000	2023	% change
Anesthesia	234	308	32%
DME	1215	2546	110%
E&M	193	650	237%
Imaging	533	1044	96%
Procedure	4730	6730	42%
Test	1175	2645	125%
Treatment	586	1837	213%

Appendix Table 3

Number of services provided to, and total amount Medicare paid (after deductible and coinsurance amounts) for, original Medicare (fee-for-service) Part B (Medical Insurance) beneficiaries by physicians and other healthcare professionals, 2019

RBCS category	RBCS subcategory	Tot_Srvcs	tot_mdcr_pymt_amt
		3,277,811,140	**$104,144,090,242**
Anesthesia		**2,239,251**	**$31,189,727**
Anesthesia	Anesthesia	2,239,251	$31,189,727
DME		**4,658,401**	**$381,779,429**
DME	Drugs Administered Through DME	1,628,681	$106,963,103
DME	Hospital Beds	.	.
DME	Medical/Surgical Supplies	2,063,786	$198,550,559
DME	Orthotic Devices	937,746	$55,888,996
DME	Other DME	28,188	$20,376,771
DME	Oxygen and Supplies	.	.
DME	Wheelchairs	.	.
E&M		**500,321,352**	**$35,656,662,635**
E&M	Behavioral Health Services	22,737,039	$1,386,854,006
E&M	Care Management/Coordination	11,465,795	$725,031,097
E&M	Critical Care Services	6,463,481	$1,094,042,314
E&M	E&M - Miscellaneous	1,853,204	$58,655,018
E&M	Emergency Department Services	20,109,397	$2,132,900,483
E&M	Home Services	5,095,032	$344,616,889
E&M	Hospice	29,846	$2,409,557
E&M	Hospital Inpatient Services	102,802,158	$7,913,501,526
E&M	Nursing Facility Services	33,124,115	$2,186,033,052
E&M	Observation Care Services	5,244,388	$492,207,422
E&M	Office/Outpatient Services	265,749,980	$17,501,283,446
E&M	Ophthalmological Services	25,646,917	$1,819,127,825
Imaging		**329,546,396**	**$8,483,260,774**
Imaging	CT Scan	25,091,974	$1,548,769,415
Imaging	Imaging - Miscellaneous	10,774,938	$325,671,359
Imaging	Magnetic Resonance	8,466,701	$921,101,901
Imaging	Nuclear	54,719,432	$1,301,686,775
Imaging	Standard X-ray	195,200,334	$2,274,239,893
Imaging	Ultrasound	35,293,017	$2,111,791,431

Other		**159,925,918**	**$5,012,055,863**
Other	Ambulance	154,848,389	$4,778,086,295
Other	Enteral and Parenteral	.	.
Other	Vision, Hearing, and Speech Services	5,077,529	$233,969,568
Procedure		**146,423,171**	**$20,111,558,429**
Procedure	Breast	478,641	$180,376,831
Procedure	Cardiovascular	3,229,838	$1,153,362,216
Procedure	Digestive/Gastrointestinal	10,721,566	$2,234,866,302
Procedure	Eye	18,292,768	$3,323,358,520
Procedure	Hematology	50,435	$6,925,718
Procedure	Musculoskeletal	26,776,916	$5,418,376,809
Procedure	Other Organ Systems	11,674,529	$2,020,100,414
Procedure	Skin	71,507,627	$3,731,993,771
Procedure	Vascular	3,690,851	$2,042,197,848
Test		**536,936,656**	**$10,083,520,240**
Test	Anatomic Pathology	40,229,670	$1,651,091,292
Test	Cardiography	45,430,016	$945,716,100
Test	General Laboratory	413,661,498	$4,631,410,450
Test	Molecular Testing	9,496,629	$1,919,929,139
Test	Neurologic	4,737,574	$628,886,819
Test	Pulmonary	5,592,547	$150,821,280
Test	Test - Miscellaneous	17,788,722	$155,665,160
Treatment		**1,597,759,995**	**$24,384,063,145**
Treatment	Chemotherapy	283,705,205	$5,964,994,014
Treatment	Dialysis	6,052,623	$841,313,231
Treatment	Injections and Infusions (nononcologic)	1,106,558,577	$11,883,772,329
Treatment	Physical, Occupational, and Speech Therapy	145,953,767	$3,233,643,411
Treatment	Radiation Oncology	12,591,193	$1,583,723,255
Treatment	Spinal Manipulation	20,536,624	$560,253,064
Treatment	Treatment - Miscellaneous	22,362,006	$316,363,842

Appendix Table 4
HCPCS codes (listed in order of year of HCPCS code establishment) covered in at least one LCD for A02.1 Salmonella sepsis

year_hcpcs	hcpcs	long_description
1982	93005	ELECTROCARDIOGRAM, ROUTINE ECG WITH AT LEAST 12 LEADS; TRACING ONLY, WITHOUT INTERPRETATION AND REPORT
1982	93000	ELECTROCARDIOGRAM, ROUTINE ECG WITH AT LEAST 12 LEADS; WITH INTERPRETATION AND REPORT
1982	93010	ELECTROCARDIOGRAM, ROUTINE ECG WITH AT LEAST 12 LEADS; INTERPRETATION AND REPORT ONLY
1982	93320	DOPPLER ECHOCARDIOGRAPHY, PULSED WAVE AND/OR CONTINUOUS WAVE WITH SPECTRAL DISPLAY (LIST SEPARATELY IN ADDITION TO CODES FOR ECHOCARDIOGRAPHIC IMAGING); COMPLETE
1984	93040	RHYTHM ECG, 1-3 LEADS; WITH INTERPRETATION AND REPORT
1984	93041	RHYTHM ECG, 1-3 LEADS; TRACING ONLY WITHOUT INTERPRETATION AND REPORT
1984	93042	RHYTHM ECG, 1-3 LEADS; INTERPRETATION AND REPORT ONLY
1984	87188	SUSCEPTIBILITY STUDIES, ANTIMICROBIAL AGENT; MACROBROTH DILUTION METHOD, EACH AGENT
1984	87190	SUSCEPTIBILITY STUDIES, ANTIMICROBIAL AGENT; MYCOBACTERIA, PROPORTION METHOD, EACH AGENT
1984	87186	SUSCEPTIBILITY STUDIES, ANTIMICROBIAL AGENT; MICRODILUTION OR AGAR DILUTION (MINIMUM INHIBITORY CONCENTRATION [MIC] OR BREAKPOINT), EACH MULTI-ANTIMICROBIAL, PER PLATE
1984	87181	SUSCEPTIBILITY STUDIES, ANTIMICROBIAL AGENT; AGAR DILUTION METHOD, PER AGENT (EG, ANTIBIOTIC GRADIENT STRIP)
1984	87184	SUSCEPTIBILITY STUDIES, ANTIMICROBIAL AGENT; DISK METHOD, PER PLATE (12 OR FEWER AGENTS)
1988	87187	SUSCEPTIBILITY STUDIES, ANTIMICROBIAL AGENT; MICRODILUTION OR AGAR DILUTION, MINIMUM LETHAL CONCENTRATION (MLC), EACH PLATE (LIST SEPARATELY IN ADDITION TO CODE FOR PRIMARY PROCEDURE)
1989	93312	ECHOCARDIOGRAPHY, TRANSESOPHAGEAL, REAL-TIME WITH IMAGE DOCUMENTATION (2D) (WITH OR WITHOUT M-MODE RECORDING); INCLUDING PROBE PLACEMENT, IMAGE ACQUISITION, INTERPRETATION AND REPORT
1990	93325	DOPPLER ECHOCARDIOGRAPHY COLOR FLOW VELOCITY MAPPING (LIST SEPARATELY IN ADDITION TO CODES FOR ECHOCARDIOGRAPHY)
1990	93321	DOPPLER ECHOCARDIOGRAPHY, PULSED WAVE AND/OR CONTINUOUS WAVE WITH SPECTRAL DISPLAY (LIST SEPARATELY IN ADDITION TO CODES FOR ECHOCARDIOGRAPHIC IMAGING); FOLLOW-UP OR LIMITED STUDY (LIST SEPARATELY IN ADDITION TO CODES FOR
1993	93313	ECHOCARDIOGRAPHY, TRANSESOPHAGEAL, REAL-TIME WITH IMAGE DOCUMENTATION (2D) (WITH OR WITHOUT M-MODE RECORDING); PLACEMENT OF TRANSESOPHAGEAL PROBE ONLY
1993	93314	ECHOCARDIOGRAPHY, TRANSESOPHAGEAL, REAL-TIME WITH IMAGE DOCUMENTATION (2D) (WITH OR WITHOUT M-MODE RECORDING); IMAGE ACQUISITION, INTERPRETATION AND REPORT ONLY
1997	93317	TRANSESOPHAGEAL ECHOCARDIOGRAPHY FOR CONGENITAL CARDIAC ANOMALIES; IMAGE ACQUISITION, INTERPRETATION AND REPORT ONLY

Appendix Table 4
HCPCS codes (listed in order of year of HCPCS code establishment) covered in at least one LCD for A02.1 Salmonella sepsis

year_hcpcs	hcpcs	long_description
1997	93316	TRANSESOPHAGEAL ECHOCARDIOGRAPHY FOR CONGENITAL CARDIAC ANOMALIES; PLACEMENT OF TRANSESOPHAGEAL PROBE ONLY
1997	93315	TRANSESOPHAGEAL ECHOCARDIOGRAPHY FOR CONGENITAL CARDIAC ANOMALIES; INCLUDING PROBE PLACEMENT, IMAGE ACQUISITION, INTERPRETATION AND REPORT
2001	93318	ECHOCARDIOGRAPHY, TRANSESOPHAGEAL (TEE) FOR MONITORING PURPOSES, INCLUDING PROBE PLACEMENT, REAL TIME 2-DIMENSIONAL IMAGE ACQUISITION AND INTERPRETATION LEADING TO ONGOING (CONTINUOUS) ASSESSMENT OF (DYNAMICALLY CHANGING)
2001	87185	SUSCEPTIBILITY STUDIES, ANTIMICROBIAL AGENT; ENZYME DETECTION (EG, BETA LACTAMASE), PER ENZYME
2006	76377	3D RENDERING WITH INTERPRETATION AND REPORTING OF COMPUTED TOMOGRAPHY, MAGNETIC RESONANCE IMAGING, ULTRASOUND, OR OTHER TOMOGRAPHIC MODALITY WITH IMAGE POSTPROCESSING UNDER CONCURRENT SUPERVISION; REQUIRING IMAGE POSTPROC
2006	76376	3D RENDERING WITH INTERPRETATION AND REPORTING OF COMPUTED TOMOGRAPHY, MAGNETIC RESONANCE IMAGING, ULTRASOUND, OR OTHER TOMOGRAPHIC MODALITY WITH IMAGE POSTPROCESSING UNDER CONCURRENT SUPERVISION; NOT REQUIRING IMAGE POST
2008	C8926	TRANSESOPHAGEAL ECHOCARDIOGRAPHY (TEE) WITH CONTRAST, OR WITHOUT CONTRAST FOLLOWED BY WITH CONTRAST, FOR CONGENITAL CARDIAC ANOMALIES; INCLUDING PROBE PLACEMENT, IMAGE ACQUISITION, INTERPRETATION AND REPORT
2008	C8925	TRANSESOPHAGEAL ECHOCARDIOGRAPHY (TEE) WITH CONTRAST, OR WITHOUT CONTRAST FOLLOWED BY WITH CONTRAST, REAL TIME WITH IMAGE DOCUMENTATION (2D) (WITH OR WITHOUT M-MODE RECORDING); INCLUDING PROBE PLACEMENT, IMAGE ACQUISITION
2008	C8927	TRANSESOPHAGEAL ECHOCARDIOGRAPHY (TEE) WITH CONTRAST, OR WITHOUT CONTRAST FOLLOWED BY WITH CONTRAST, FOR MONITORING PURPOSES, INCLUDING PROBE PLACEMENT, REAL TIME 2-DIMENSIONAL IMAGE ACQUISITION AND INTERPRETATION LEADING
2015	87505	INFECTIOUS AGENT DETECTION BY NUCLEIC ACID (DNA OR RNA); GASTROINTESTINAL PATHOGEN (EG, CLOSTRIDIUM DIFFICILE, E. COLI, SALMONELLA, SHIGELLA, NOROVIRUS, GIARDIA), INCLUDES MULTIPLEX REVERSE TRANSCRIPTION, WHEN
2015	93355	ECHOCARDIOGRAPHY, TRANSESOPHAGEAL (TEE) FOR GUIDANCE OF A TRANSCATHETER INTRACARDIAC OR GREAT VESSEL(S) STRUCTURAL INTERVENTION(S) (EG, TAVR, TRANSCATHETER PULMONARY VALVE REPLACEMENT, MITRAL VALVE REPAIR, PARAVALVULAR RE
2022	93319	3D ECHOCARDIOGRAPHIC IMAGING AND POSTPROCESSING DURING TRANSESOPHAGEAL ECHOCARDIOGRAPHY, OR DURING TRANSTHORACIC ECHOCARDIOGRAPHY FOR CONGENITAL CARDIAC ANOMALIES, FOR THE ASSESSMENT OF CARDIAC STRUCTURE(S) (EG, CARDIAC C

Appendix Table 5

Calculation of two alternative measures of innovation during 1999-2019 for two hypothetical diseases

	disease A	disease B
year in which first HCPCS code was established	1998	1998
year in which second (and last) HCPCS code was established	2000	2018
Number of HCPCS codes ever established		
1999	1	1
2019	2	2
Mean vintage of HCPCS codes ever established		
1999	1998	1998
2019	1999	2008

Appendix Table 6

1999 and 2019 mortality and HCPCS data for the top 38 diseases, ranked by number of deaths during 1999-2019

	n_deaths	n_deaths		yll75		age_death		n_hcpcs		vint_hcpcs	
358 Cause Recode (ICD-10-CM codes)	**1999-2019**	**1999**	**2019**	**1999**	**2019**	**1999**	**2019**	**1999**	**2019**	**1999**	**2019**
215 All other forms of chronic ischemic heart disease (I20, I25.1-I25.9)	4,423,540	255,317	186,567	823,600	610,454	79.3	79.9	144	291	1990.0	2000.0
93 Of trachea, bronchus and lung (C33-C34)	3,248,862	152,235	139,814	1,088,439	811,992	70.0	72.3	105	229	1986.2	1999.4
211 Acute myocardial infarction (I21-I22)	2,914,111	199,772	104,543	932,348	610,926	76.1	74.6	115	213	1989.8	1998.9
267 Other chronic obstructive pulmonary disease (J44)	2,561,334	99,622	144,869	307,373	511,028	76.9	77.1	136	205	1987.9	1995.0
175 Organic dementia (F01, F03)	1,864,109	28,712	115,125	9,951	50,236	86.8	87.2	82	184	1988.4	1999.9
189 Alzheimer's disease (G30)	1,738,728	44,543	121,539	20,356	53,644	85.1	86.6	113	189	1987.6	1996.8
159 Diabetes mellitus (E10-E14)	1,574,335	68,457	87,795	444,144	645,569	72.7	71.7	234	435	1988.2	1998.2
238 Stroke, not specified as hemorrhage or infarction (I64)	1,495,939	91,121	53,818	163,806	154,125	81.8	80.7				
214 Atherosclerotic cardiovascular disease, so described (I25.0)	1,325,964	72,150	66,459	371,576	501,329	76.2	72.1	1	1	1984.0	1984.0
230 Congestive heart failure (I50.0)	1,182,324	50,833	65,803	79,452	139,744	83.4	83.3	0	1	.	2011.0
257 Pneumonia due to other or unspecified organisms (J16,J18)	1,056,692	57,642	39,123	157,423	165,789	81.9	78.8	86	124	1987.0	1993.7
228 Conduction disorders and cardiac dysrhythmias (I44-I49)	946,871	39,973	56,886	191,077	250,278	77.4	78.4	161	326	1988.6	1999.4
327 Renal failure (N17-N19)	926,348	34,583	50,534	148,826	237,298	77.1	76.6	109	183	1988.9	1997.5
81 Colon (C18)	917,942	48,463	40,710	284,574	298,696	73.4	71.9	92	277	1987.1	2004.1
104 Malignant neoplasm of breast (C50)	877,158	41,557	42,826	432,312	396,333	67.7	69.3	74	291	1986.2	2006.1
125 Other malignant neoplasms of other and unspecified sites (C76-C80, C97)	855,158	43,894	43,506	311,321	274,485	71.5	72.9	326	621	1987.3	1998.1
88 Of pancreas (C25)	764,739	29,113	45,956	194,367	290,714	71.6	71.9	68	266	1986.6	2006.0
23 Septicemia (A40-A41)	751,592	30,434	38,380	170,397	245,501	75.4	73.8	95	150	1987.0	1995.0
207 Hypertensive heart disease (I11)	730,565	22,774	55,581	150,628	386,128	74.9	75.0	98	179	1989.3	1998.3

Appendix Table 6

1999 and 2019 mortality and HCPCS data for the top 38 diseases, ranked by number of deaths during 1999-2019

	n_deaths	n_deaths		yll75		age_death		n_hcpcs		vint_hcpcs	
358 Cause Recode (ICD-10-CM codes)	**1999-2019**	**1999**	**2019**	**1999**	**2019**	**1999**	**2019**	**1999**	**2019**	**1999**	**2019**
194 All other diseases of nervous system (G10-G14, G23-G25, G31, G36-G37, G43-G44, G47-G72, G81-G98)	651,709	17,949	65,572	209,878	346,098	66.2	77.1	365	723	1987.7	1998.4
113 Of prostate (C61)	618,636	31,747	31,673	72,001	90,218	78.5	78.5	66	247	1985.9	2005.5
278 All other diseases of respiratory system (J80-J84,J93-J98)	614,044	22,425	40,745	119,112	185,295	74.8	76.3	175	253	1987.5	1993.9
239 Other cerebrovascular diseases and their sequelae (I67, I69)	612,038	29,530	44,901	51,116	90,581	82.5	83.4	256	491	1988.0	1998.2
236 Intracerebral and other intracranial hemorrhage (I61-I62)	578,363	25,496	28,179	172,279	169,764	72.6	74.5	80	146	1988.5	1997.5
227 Cardiomyopathy (I42)	506,725	27,167	20,389	246,647	185,673	70.3	70.8	123	242	1989.5	1999.3
188 Parkinson's disease (G20-G21)	479,226	14,596	35,327	12,716	35,517	81.4	81.9	152	261	1987.8	1997.3
129 Non-Hodgkin's lymphoma (C82-C85)	438,561	22,831	20,316	172,117	109,555	70.8	74.4	199	337	1987.5	1997.4
273 Pneumonitis due to food and vomit (J69.0)	373,081	15,245	19,192	36,475	67,631	81.7	80.0	1	1	1984.0	1984.0
206 Essential (primary) hypertension (I10)	349,862	9,920	23,089	36,645	105,577	79.3	78.2	61	119	1988.9	1997.3
300 Fibrosis and cirrhosis of liver (K74)	344,866	13,879	20,230	167,741	212,661	64.5	66.3	78	130	1988.0	1996.8
298 Alcoholic liver disease (K70)	344,684	11,971	24,176	241,047	444,014	55.2	56.9	81	133	1987.8	1996.5
85 Liver (C22.0, C22.2-C22.9)	320,165	9,847	20,190	92,753	156,621	68.0	69.6	0	1	.	2019.0
225 Nonrheunatic aortic valve disorders (I35)	310,449	12,218	16,141	25,205	30,206	82.3	84.5	103	186	1989.5	1998.4
118 Of bladder (C67)	302,861	11,916	16,812	47,796	57,232	76.0	77.9	55	130	1985.9	2000.8
109 Of ovary (C56)	300,898	13,641	13,469	116,141	106,071	69.2	70.1	57	235	1986.3	2006.3
293 Vascular disorders and obstruction of intestine without hernia (K55-K56)	299,166	13,747	14,674	49,234	66,530	78.3	77.2	94	181	1987.5	1998.4
122 Of brain (C71)	297,989	12,487	16,909	194,836	211,735	60.8	64.3	73	226	1987.1	2003.2
77 Of esophagus (C15)	294,546	11,923	15,985	100,916	122,814	68.8	69.8	78	157	1986.2	1998.9

Appendix Table 7

Estimates of β_k from model $\ln(\text{mortality}_{dt}) = \beta_k \ln(\text{n_hcpcs}_{d,t-k}) + \alpha_d + \delta_t + \varepsilon_{dt}$

k (lag)	Estimate	Std. Err.	Z	Pr > |Z|		k (lag)	Estimate	Std. Err.	Z	Pr > |Z|
	A. $\text{mortality}_{dt} = \text{yll85}_{dt}$						B. $\text{mortality}_{dt} = \text{yll75}_{dt}$			
0	**-0.1769**	**0.0853**	**-2.07**	**0.0380**		0	**-0.1991**	**0.0827**	**-2.41**	**0.0160**
1	**-0.1821**	**0.0889**	**-2.05**	**0.0405**		1	**-0.2096**	**0.0861**	**-2.43**	**0.0149**
2	-0.1803	0.0928	-1.94	0.0521		2	**-0.2156**	**0.0895**	**-2.41**	**0.0160**
3	-0.1784	0.0979	-1.82	0.0684		3	**-0.2184**	**0.0926**	**-2.36**	**0.0183**
4	-0.1691	0.1073	-1.57	0.1153		4	**-0.2147**	**0.0986**	**-2.18**	**0.0295**
5	-0.1465	0.1194	-1.23	0.2200		5	-0.1990	0.1075	-1.85	0.0643
6	-0.1261	0.1318	-0.96	0.3385		6	-0.1800	0.1175	-1.53	0.1256
7	-0.1032	0.1484	-0.70	0.4869		7	-0.1577	0.1314	-1.20	0.2302
8	-0.1449	0.1855	-0.78	0.4348		8	-0.1764	0.1600	-1.10	0.2703
	C. $\text{mortality}_{dt} = \text{yll65}_{dt}$						D. $\text{mortality}_{dt} = \text{age_death}_{dt}$			
0	**-0.1978**	**0.0732**	**-2.70**	**0.0069**		0	0.0202	0.0118	1.71	0.0873
1	**-0.2108**	**0.0771**	**-2.73**	**0.0062**		1	0.0217	0.0123	1.77	0.0770
2	**-0.2214**	**0.0815**	**-2.72**	**0.0066**		2	0.0235	0.0127	1.85	0.0643
3	**-0.2261**	**0.0858**	**-2.64**	**0.0084**		3	0.0250	0.0131	1.91	0.0563
4	**-0.2224**	**0.0937**	**-2.37**	**0.0177**		4	0.0269	0.0141	1.91	0.0561
5	**-0.2088**	**0.1051**	**-1.99**	**0.0470**		5	0.0288	0.0155	1.86	0.0630
6	-0.1858	0.1182	-1.57	0.1160		6	0.0297	0.0171	1.73	0.0829
7	-0.1562	0.1344	-1.16	0.2451		7	0.0317	0.0196	1.62	0.1051
8	-0.1493	0.1616	-0.92	0.3553		8	0.0322	0.0223	1.45	0.1483
	E. $\text{mortality}_{dt} = \text{n_deaths}_{dt}$									
0	-0.1205	0.1273	-0.95	0.3441						
1	-0.0872	0.1374	-0.63	0.5258						
2	-0.0369	0.1576	-0.23	0.8146						
3	0.0077	0.1896	0.04	0.9678						
4	0.0758	0.2354	0.32	0.7474						
5	0.1624	0.2839	0.57	0.5672						
6	0.2239	0.3201	0.70	0.4844						
7	0.3033	0.3632	0.83	0.4038						
8	0.2350	0.4027	0.58	0.5595						

Each estimate is from a separate model.

Estimates in bold are statistically significant (p-value < .05).

Appendix Table 8

MORTALITY OF BLACKS

Estimates of β_k from model $\ln(mortality_{dt}) = \beta_k\ vint_hcpcs_{d,t-k} + \alpha_d + \delta_t + \varepsilon_{dt}$

k (lag)	Estimate	Std. Err.	Z	Pr > |Z|		k (lag)	Estimate	Std. Err.	Z	Pr > |Z|
	A. $mortality_{dt} = yll85_{dt}$						B. $mortality_{dt} = yll75_{dt}$			
0	-0.0048	0.0059	-0.82	0.4134		0	-0.0060	0.0063	-0.95	0.3447
1	-0.0049	0.0059	-0.82	0.4137		1	-0.0061	0.0063	-0.97	0.3330
2	-0.0045	0.0061	-0.73	0.4657		2	-0.0061	0.0065	-0.94	0.3479
3	-0.0040	0.0062	-0.65	0.5173		3	-0.0061	0.0066	-0.92	0.3557
4	-0.0020	0.0062	-0.32	0.7497		4	-0.0045	0.0067	-0.66	0.5078
5	0.0009	0.0063	0.15	0.8826		5	-0.0022	0.0069	-0.32	0.7515
6	0.0046	0.0069	0.67	0.5016		6	0.0011	0.0077	0.14	0.8896
7	0.0088	0.0081	1.09	0.2778		7	0.0042	0.0091	0.46	0.6433
8	0.0112	0.0109	1.03	0.3047		8	0.0049	0.0122	0.40	0.6866
	C. $mortality_{dt} = yll65_{dt}$						D. $mortality_{dt} = age_death_{dt}$			
0	-0.0088	0.0070	-1.27	0.2041		0	0.0017	0.0011	1.54	0.1247
1	-0.0090	0.0068	-1.31	0.1886		1	0.0018	0.0011	1.60	0.1106
2	-0.0091	0.0071	-1.29	0.1959		2	0.0020	0.0012	1.71	0.0867
3	-0.0094	0.0072	-1.30	0.1934		3	0.0022	0.0012	1.86	0.0624
4	-0.0075	0.0074	-1.03	0.3052		4	0.0024	0.0012	1.95	0.0512
5	-0.0052	0.0076	-0.69	0.4878		5	**0.0027**	**0.0013**	**2.04**	**0.0410**
6	-0.0016	0.0086	-0.18	0.8551		6	**0.0029**	**0.0015**	**1.99**	**0.0469**
7	0.0014	0.0104	0.14	0.8919		7	**0.0033**	**0.0016**	**2.02**	**0.0432**
8	0.0023	0.0145	0.16	0.8711		8	**0.0044**	**0.0020**	**2.23**	**0.0260**
	E. $mortality_{dt} = n_deaths_{dt}$									
0	-0.0039	0.0088	-0.45	0.6540						
1	-0.0029	0.0087	-0.34	0.7369						
2	-0.0007	0.0086	-0.08	0.9365						
3	0.0018	0.0089	0.20	0.8415						
4	0.0064	0.0097	0.66	0.5075						
5	0.0126	0.0111	1.14	0.2549						
6	0.0193	0.0127	1.52	0.1295						
7	0.0290	0.0155	1.87	0.0622						
8	**0.0404**	**0.0202**	**2.01**	**0.0449**						

Each estimate is from a separate model.

Estimates in bold are statistically significant (p-value < .05).